

## POLARIZED H<sup>-</sup> ION SOURCE PERFORMANCE DURING THE 2003 RHIC RUN\*

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### *Abstract*

The performance of the RHIC Optically-Pumped Polarized H<sup>-</sup> Ion Source (OPPIS) for the 2003 run in AGS and RHIC is reviewed. The OPPIS met the RHIC requirement for the beam intensity with the reliable delivery of ~0.5 mA polarized H<sup>-</sup> ion current in 400 microsecond pulses (maximum current was 1.5 mA). The beam intensity after the 200 MeV linac was  $5-6 \times 10^{11}$  H<sup>-</sup>/pulse, which exceeded present RHIC program requirements, even after considerable controlled beam scraping in the Booster to reduce the 6-D emittance in the AGS. Magnetic field shape optimization at the source ionizer cell entrance greatly reduced the extraction high-voltage discharge current in the crossed electric and magnetic fields. As a result, reliable spark free operation was achieved at 7 Hz repetition rate. Polarization optimization studies have resulted in  $82 \pm 2\%$  beam polarization as measured in a 200 MeV polarimeter.

### INTRODUCTION

The OPPIS has been operating since early January, 2003, for RHIC polarized beam setup and commissioning, followed directly by a RHIC spin physics run. Therefore, we are now nearing the end of ~4½ months of continuous running of the source. During this time, source reliability has been very good. The intensity can easily exceed the requirement for RHIC, so the source is typically operating at ~400-500 µA, which is less than the maximum output current. Polarization is typically 75-80%. An ~8 hour weekly maintenance period has been required for the source, but one can be flexible in the scheduling of the maintenance, so it can be done either along with other machine maintenance, or during a long RHIC store. This maintenance has primarily been on the ECR primary proton source, while laser systems and vapor cells have been trouble free.

### OPPIS SOURCE

The OPPIS is shown schematically in Fig. 1. This source was developed in a collaboration between Brookhaven, KEK, INR (Moscow), and TRIUMF. It is based on components from the KEK OPPIS, was upgraded at TRIUMF for high current operation, shipped to BNL in the fall of 1999, and has undergone

considerable further optimization at BNL. The source has a 115 cm long superconducting solenoid with three separately adjustable coils. An ECR source operating at 29 GHz, ~0.8 kW, sits in the solenoid in a resonant field region of 10 kG. It produces the primary proton beam of ~80 mA at an energy of ~3 keV, with a multi-aperture extraction system (120 holes). Also located in the solenoid, in a field of 27 kG, is a Rb vapor cell. This vapor is polarized via optical pumping using circular polarized light from a 1 kW, flashlamp pumped Cr:LiSAF laser. Protons are converted to polarized hydrogen atoms via pickup of a polarized electron from the Rb. These 3 keV atoms are then converted to H<sup>-</sup> by electron pickup in a Na vapor jet cell, located in a separate solenoidal field of 1.4 kG. The entire Na jet assembly is biased to a voltage of -32 kV, so the H<sup>-</sup> ions are accelerated to a final total energy of 35 keV while leaving the source, for injection into the RFQ. Details on the source can be found in [1].

A new 35 keV low energy beam transport (LEBT) was designed to allow injection into the existing RFQ without interfering with high intensity, unpolarized beam operations, while preserving polarization and giving the desired vertical spin alignment. The 35 keV beam from OPPIS passes through a pulsed dipole, so one is able to interleave at ~7 Hz rep rate polarized and high current unpolarized beam pulses before injection into an RFQ. (High current pulses go to an isotope production facility at the end of linac). Transmission from the polarized source to the end of the linac is typically ~50%. One is able to monitor beam polarization at 200 MeV with both p-carbon and p-deuteron polarimeters. When polarized beam is injected into Booster at ~0.25 Hz, a second source pulse is sent to the 200 MeV polarimeter for continuous online monitoring of polarization. The design and performance of this new injection line is described in [2,3].

The control system allows one to produce source pulses in an arbitrary spin sequence. For example, bunches in one RHIC ring are filled with the sequence ++--++--, and bunches in the other ring are filled as +-+-+-. Also, it is convenient that one can produce unpolarized beam pulses with no change in beam parameters by merely inhibiting the laser pulses.

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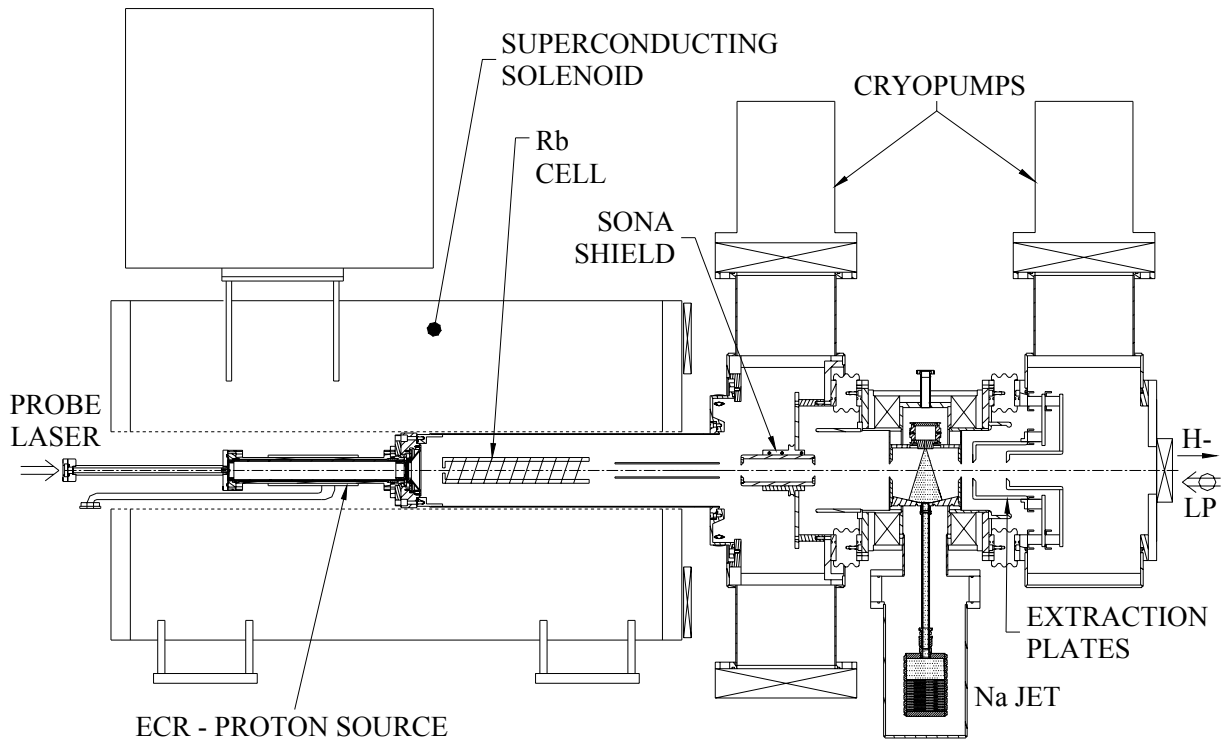


Figure 1: Schematic of the OPPIS source.

### OPPIS PERFORMANCE

The source performance has been very good. The  $\sim 0.5$  mA current that we are typically running is quite a bit less than what we can achieve when ECR power, vapor cell temperatures, etc. are all at their peak values, but this current satisfies the program requirements while reducing demands on the source. Indeed, the current is high enough that 80-90% of the current is scraped in a controlled fashion in the Booster in order to reduce both the transverse and longitudinal emittance of the beam in the AGS. This smaller emittance results in less depolarization in the AGS.

With the long continuous runs for RHIC setup/physics, much of the development effort has gone towards refinements to improve long term stability, reliability, and maintainability. Some of the improvements have happened during the course of the run.

#### *Laser System*

The 1 kW, flashlamp pumped Cr:LiSAF laser has operated maintenance free for the entire 4.5 month period. The Rb vapor thickness and polarization is measured by the Faraday rotation technique. The measurement provides a continuous polarization confirmation signal for the spin direction pattern of bunches injected into RHIC.

#### *Auxiliary Solenoid Coil*

It had been noticed that there was a sensitivity of extractor voltage holding to the precise positioning of the main superconducting solenoid coil. In order to allow an

independent control of this sensitivity to the detailed magnetic field shape in the extraction region, a room temperature coil was added at the end of the superconducting solenoid. This 40-turn “pancake” solenoid (2 turn, 20 layers) has proved very effective in eliminating sparking of the 32 keV extraction voltage. The correction coil field direction is opposite to the superconducting solenoid field. It helps to reduce significantly the superconducting solenoid stray field at large radii ( $\sim 10$  cm). Magnetic field calculations suggest that one is eliminating a region of crossed E and B fields at these large radii, where there was a tendency for a glow discharge to be sustained. The drain current on the extractor power supply can be reduced from  $\sim 400$  mA when the coil is off, to essentially zero with the coil at  $\sim 130$  A.

The coil also allows one to control the Sona transition position, which has resulted in smaller longitudinal field gradient. For maximum polarization, this gradient must be less than 0.5 G/cm at the zero crossing point. With the correction coil the gradient was reduced to less than 0.15 G/cm.

#### *ECR Source Performance*

The ECR source operates at 29 GHz,  $\sim 0.8$  kW, and produces the primary proton beam of  $\sim 80$  mA at an energy of  $\sim 3$  keV, with a 120 aperture extraction system. The source has no hexapolar field, and the discharge chamber of the source has a quartz liner. This source has evolved from its original configuration, in which it was operated cw. Since we require only very low duty factor, pulsed operation of the ECR has been explored. A  $\sim 30\%$

enhancement in output can be observed in pulsed operation, and the gas flow from the source can be reduced. In addition, the ratio of atomic to molecular ions from the ECR was improved in pulsed operation (resulting in higher beam polarization). An additional enhancement in performance comes from running with a slight admixture (a few percent) of oxygen with the hydrogen feed. Starting with the optimized conditions of a newly cleaned and installed ECR source, however, one observed a reduction in the pulsed output over time, and so the source would periodically be switched back to cw mode for a "re-conditioning". This has only limited effectiveness, and there has been a 30-60% reduction in output on about a 1 week time scale. Since the source output exceeds our requirements for RHIC, we start with the current cut back from the maximum achievable, by reducing the Rb vapor cell thickness below its optimum. As the ECR output degrades, we make up for this by increasing the Rb thickness. After  $\sim 7$  days, we can no longer compensate for the reduced ECR output, and have to remove and clean the ECR ( $\sim 8$  hour maintenance, which is scheduled to fit with either a machine maintenance, or during a long RHIC store). The reduction in output seems to be coming primarily from a gradual contamination of the inner quartz wall of the ECR chamber, and much of it seems to be sputtered Mo coming back from the extraction grids. Most recently, we have found some improvement in stability by operating the ECR with a cw power of  $\sim 500$  W, which is bumped up to  $\sim 750$  W during beam time to enhance the output current.

### *Reducing $H_2^+$ ions from the ECR*

We have found that there is some reduction in  $H^-$  polarization coming from the  $H_2^+$  ion component extracted from the ECR along with the  $H^+$ . When these molecular ions break up, with half the 3 keV  $H^+$  energy, they can be ionized in the Na cell, resulting in a 33.5 keV

$H^-$  component along with the 35 keV  $H^-$  beam. This lower energy component has low polarization. It has been shown both in simulations and experimentally that under many conditions the LEBT tune will match both energy components into the RFQ, resulting in a reduced beam polarization.

We have managed to increase the rejection of the unwanted lower energy ions by replacing a magnetic quadrupole triplet at the exit of the source by an einzel lens, operating in the decelerating mode. Also, with careful setting of the voltages on the 3-gap extraction electrodes, the lower energy ions can be rejected further. These changes have resulted in a suppression in the transport line of  $H^-$  ions coming from  $H_2^+$  by almost an order of magnitude. In addition, as mentioned earlier,  $H_2^+$  output from the ECR is reduced in pulsed operation, and in dc operation an  $O_2$  admixture reduces the molecular ions.

## REFERENCES

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